METHOD AND UNIT FOR SUBSTRACTING QUANTIZATION NOISE FROM A PCM SIGNAL

The invention relates to a method and a unit for substracting quantization noise from a PCM signal.

Pulse code modulation (PCM) is a widely used technique to represent e.g. audio signals in the digital domain. Linear PCM uses evenly distributed quantization levels

5 whereas the logarithmic PCM uses a distribution where small-signal amplitudes are quantized using more closely spaced levels than large-signal amplitudes. An example to linear PCM is the CD-audio, which uses 16 bits to represent uniformly distributed signal levels.

Fig. 5 illustrates the quantization of a linear coded PCM signal amplitudes

10 (curve (a)) and of two logarithmically coded PCM signal amplitudes (curve (b) and (c)). Cuve b illustrates the quantization of μ-law coded PCM signal amplitudes, wherein the μ-law has an input-output magnitude characteristic of the form:

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$$|y| = \frac{\log(1 + \mu|s|)}{\log(1 + \mu)},\qquad (1)$$

where $|s|$ is the magnitude of the input, $|y|$ is the magnitude of the output and μ is a parameter that is selected to give the desired compression characteristic.

20 In Fig. 5 curve c) illustrates the quantization of A-law coded PCM signal amplitudes, wherein the A-law has an input-output magnitude characteristic of the form:

$$|y| = \frac{1 + \log A|s|}{1 + \log A},\qquad (2)$$

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wherein the meaning of y and s is as mentioned above and A is constant. The prior art μ-law and A-law coders are standardized by the Comité Consultatif International de Téléfonique et Télégraphique CCITT as the G.711 64kbit/s PCM. The quantizer characteristics of the G.711

are disclosed in: N.S. Jayant and P. Noll, "Digital Coding of Waveforms", Englewood Cliffs NJ: Prentice-Hall, 1984.

The quantized sample values of a signal may be modeled mathematically as

$$s*[n] = s[n] + q[n], \qquad (3)$$

wherein S*[n] represents the quantized value of an original unquantized sample value *s[n]* and q*[n]* represents the quantization error resulting from said quantization. The quantization error can be interpreted as undesired additive noise decreasing the quality of the original sample values s[n].

Thus, it is the object of the invention to provide a method and a unit for substracting said quantization noise from a PCM signal.

This object is solved by a method comprising the steps of:

calculating for each frame of said PCM signal a quantization noise level Bq according to the following equation:

$$B_q = \sqrt{\sum_{n=0}^{W-1} \frac{\{(s*_{min}[n] - s*_{max}[n]) \cdot w[n]\}^2}{12}}$$

wherein

n	: indicates a specific sample of the PCM signal;
$S*_{min}[n]$	: represents the minimum quantization noise level for a specific sample value s*[n] of said PCM signal;
$S*_{max}[n]$	: represents the maximum quantization noise level for the specific sample value s*[n] of the PCM signal;
w[n]	: represents a window-function; and
W	: represents the number of samples per window;

and

substracting the quantization noise as represented by said quantization noise level Bq from said PCM signal.

It is the essential idea of the invention to calculate said quantization noise levels Bq for each frame according to the claimed formula and to use any suitable (background) noise substracting method known in the art - perhaps after carrying out slight modifications - to substract the quantization noise from the PCM signal.

Throughout the whole description * indicates the content of quantization noise in the co-ordinated quantity or signal.

The window-function may be chosen arbitrarily.

The claimed formula requires the minimum quantization level $S^*_{min}[n]$ as well as on the maximum quantization level $S^*_{max}[n]$ of the sample values $s^*[n]$ of the PCM signal.

According to a first advantageous embodiment of the invention the minimum quantization level $S^*_{min}[n]$ as well as the maximum quantization level $S^*_{max}[n]$ are known from the quantization method applied for generating the PCM signal.

According to a second embodiment said quantization levels $S^*_{min}[n]$ and $S^*_{max}[n]$ are not known and must therefore be predicted according to the formulas claimed in claim 3.

Advantageously neither in the first nor in the second embodiment any additional information must transmitted together with the PCM sample values $s^*[n]$ to enable the conduction of the claimed method. This is because in the first embodiment the quantization levels and in the second embodiment reference levels i can be assumed to be known (see the last two paragraphs above) when the method for substracting the quantization noise according to the invention is carried out. Because of that advantageously bandwidth is saved.

Preferably, the noise substraction is based on a background noise substracting method and system as described in the non-prepublished European Patent application having the application number EP 01201304.1 of the same applicant. The application of said system is described later as preferred embodiment. The whole content of said patent application shall be regarded as part of the disclosure of the present application.

Finally, the above-identified object is solved by a noise substracting unit according to the subject matter of claim 9. The advantages of said unit correspond to the advantages mentioned above referring to the claimed method.

Preferably, the claimed unit and method are applied at the decoder side, i.e. just before the PCM signal is decoded again. However, nevertheless it might also be applied at the encoder side.

The description is accompanied by five figures, wherein

Fig. 1   shows a quantization noise substracting unit according to the invention including the background noise subtracting unit;

5   Fig. 2   shows an example for illustrating the correlation between reference values I and sample values S*[n];

Fig. 3   shoes a detailed illustration of a background noise substracting unit;

Fig. 4.1.   shows the spectrum of a clean male voice;

Fig. 4.2.   shows the μ-law coded version of the spectrum shown in Fig. 4.1.;

10   Fig. 4.3.   shows the μ-law coded version of the spectrum shown in Fig. 4.1. after quantization noise substraction according to the invention;

Fig. 4.4.   shows the usage array u[i] generated for applying the quantization noise substraction method to the spectrum shown in Fig. 4.2;

Fig. 5   showing quantization levels for linearly and non-linearly coded PCM-signals

15   as known in the art.

In the following a preferred embodiment of the invention will be described by referring to Figures 1-4.

Fig. 1 shows a quantization noise substracting unit 100-700 for substracting

20   quantization noise from an input linearly or logarithmically coded PCM signal.

First of all said unit comprises a quantization noise level calculating unit 100 for calculating a quantization noise level Bq for each frame of said PCM signal under consideration of both a minimum and a maximum quantization noise level $S^*_{min}[n]$, $S^*_{max}[n]$. More specifically, the quantization noise level Bq is constant for each frame of said PCM

25   signal and calculated individually for a specific frame according to the following equation:

$$B_q = \sqrt{\sum_{n=0}^{W-1} \frac{\{(s^*_{min}[n] - s^*_{(4)max}[n]) \cdot w[n]\}^2}{12}}$$

wherein

30   n   : indicates a specific sample of the PCM signal;

$S^*_{min}[n]$: represents the minimum quantization noise level for a specific sample value s*[n] of said PCM signal;

$S^*_{max}[n]$: represents the maximum quantization noise level for the specific sample value s*[n] of the PCM signal;

w[n]   : represents a window-function; and

W   : represents the number of samples per window comprising at least the specific frame for which Bq is currently calculated.

Typically, the number of samples per window is twice the number of samples per frame.

In equation 4 the term $\dfrac{\{(s^*_{min}[n] - s^*_{max}[n]) \cdot w[n]\}^2}{12} = \varepsilon$ represents the mean square value of the quantization error, i.e. the energy of the quantization noise in the current frame.

The frame size is typically 2ms.

According to a first embodiment said quantization noise levels $S^*_{min}[n]$, $S^*_{max}[n]$ are assumed to be known.

However, according to a second embodiment of the invention these quantization levels $S^*_{min}[n]$, $S^*_{max}[n]$ are not assumed to be known, e.g. because the original signals might have been quantized with different quantizers and there may have been extra scalings applied on the samples before or after coding. In these cases the quantization levels have to be predicted.

To predict the quantization levels, the entire original signal, hereinafter also referred to as waveform, is scanned to receive the sample values s*[n] of the quantized waveform. Subsequently, a check is made, if all possible representation levels i predefined due the quantization method applied to the waveform are represented (used) by at least one said sample values s*[n]. For a 16-bit linear PCM quantization method there are $2^{16} = 65536$ possible representation levels i and the result of said check is described in a so called usage table u[i] with 65536 values. The values of said usage table u[i] are either 1 (if there is at least one sample value of the whole waveform corresponding to the current representation level i) or 0 (if there is no sample value of the whole waveform corresponding to the current representation level i). Expressed mathematically

$$u[i] = \min\left(1, \sum_{n=0}^{L-1} \begin{cases} 0, & s^*[n] \neq i \\ 1, & otherwise \end{cases}\right), \quad -2^{N-1} \leq i < 2^{N-1} \qquad (5)$$

In formula (5) L is the waveform length, i.e. the number of samples of the whole waveform, and N is the number of bits used by the linear PCM quantization; in the above example N=16. This operation can be simplified by initializing all values of $u[i]$ with 0 and using formula (6):

$$u[s*[n]] = 1, \qquad 0 \le n < L \qquad (6)$$

Now equations (5) or (6) are used to find special representation levels $i_{min}[n]$ and $i_{max}[n]$ *required for predicting the desired quantization levels. More specifically,* $i_{min}[n]$ is defined as that representation level which is - startet from i[n] - the next smaller non-zero representation level for which u[n]=1 and $i_{max}[n]$ is defined as that representation level which is - started from i[n] - the next bigger non-zero representation level for which u[n]=1.

With the help of said co-ordinated representation levels the desired quantization levels are predicted or calculated according to the following equations:

$$s*_{min} = i[n] - (i[n] - i_{min}[n])/2 \qquad (7)$$
$$s*_{max} = i[n] + (i_{max}[n] - i[n])/2 \qquad (8)$$

wherein

i   : represents one out of a plurality of predefined possible representation levels;

i[n]   : represents that predefined representation level which corresponds to the sample value s*[n].

Fig. 2 illustrates the calculation of the usage array, of said special representation levels $i_{min}[n]$, $i_{max}[n]$ and of the desired quantization levels $S*_{min}[n]$, $S*_{max}[n]$ for a given waveform consisting of L=9 sample values S*[n] which are in the example distributed as shown in Tab. 1:

n	1	2	3	4	5	6	7	8	9
s*[n] =i[n]	3	2	-1	-1	2	1	1	3	-3

Tab. 1

In Fig. 2 there are provided 8 different possible representation levels i= -4, ...-1, 0, 1,..., 3 resulting from a N=3 bit linear PCM quantization. The usage array u[i] calculated according to equation (5) or (6) for the example of Tab. 1 is:

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$$u[-3] = u[-1] = u[1] = u[2] = u[3] = 1; \text{ and}$$
$$u[-4] = u[-2] = u[0] = 0$$

Now, from said usage array the reference levels $i_{min}[n]$ and $i_{max}[n]$ are

10 calculated e.g. for n=2 with s*[2]=i[2] =1 - according to the definition given above - to:

$$i_{max}[2] = 2 \text{ and } i_{min}[2] = -1$$

and the desired quantization levels result -according to equations (7) and (8) to:

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$$s*_{min} = 1 - (1 - (-1))/2 = 0$$
$$s*_{max} = 1 + (2 - 1)/2 = 1,5$$

Special care has to be taken when i[n] co-ordinated to s*[n] is the first or last

20 non-zero value in the usage-array u. One option is to allocate two extra array values $u[-2^{N-1}-1]$ and $u[2^{N-1}]$, set them both to 1 and always continue the search until a non-zero value is found.

Another question is what to do when some valid quantization levels aren't used in the waveform. Especially waveforms shorter than 1 second will result in a usage-

25 array with many unused (but valid) quantization levels. Since this usually will give a wrong result for the quantization step-size at boundaries (when the waveform is at its maximum or minimum value), the effect on the measured level of quantization noise will be small. Although an algorithm could be used to predict the unused valid quantization levels, the added value of the extra complexity is not worth the performance gain. In practice, it seems

30 to be enough to assume that the used signal levels in the waveform are the only valid levels.

After the quantization noise level Bq has been calculated either with the known or with the predicted quantization levels s*_{min} and s*_{max} it is input into a background noise substracting unit BNS 200 which is also part of said quantization noise substracting unit.

Fig. 3 shows a detailed illustration of said background noise substracting unit
200 which is embodied to substract the quantization noise from a PCM signal in the
frequency domain. It comprises a magnitude forming unit 210 for forming the magnitude
$|S^*[k]|$ of the spectrum $S^*[k]$ of the PCM signal, a signal-to-noise ratio calculating unit 220
for calculating the signal-to-noise ratio of the PCM signal according to the formula:

$$SNR\ [k] = |S^*[k]|/Bq, \qquad\qquad (9)$$

wherein Bq is noise level representing the level of quantization noise in said PCM signal.

Said signal-to-noise ratio SNR[k] is input into a filter update unit 230 for
calculating a filter magnitude F[k] according to a predefined filter algorithm based on at least
one filter update parameter. Said filter magnitude F[k] is input into a calculation unit 240 for
calculating an output spectrum $S^b[k]$ by multiplying both the real part $R\{S^*[k]\}$ and the
imaginary part $I\{S^*[k]\}$ of the spectrum $S^*[k]$ with said filter magnitude $F\{k\}$. The filter
update parameter and thus also the filter magnitude F[k] are preferably adjusted such that
output spectrum $S^b[k]$ is at least substantially free of quantization noise.

Because said background noise substracting unit 200 is embodied to carry out
the substraction of the quantization noise in the frequency domain, the quantization noise
substracting unit further comprises several units for computing the spectrum $S^*[k]$ of the
PCM signal to be input into said background noise substracting unit 200 and for transforming
the spectrum $S^b[k]$ output by said unit 200 back into a time domain signal. These units are
described in the following paragraphs.

Referring back to Fig. 1 the quantization noise substracting unit further
comprises a first window block 300 for generating a weighted PCM signal $s^*_w[n]$ by
weighting the frames of the input PCM sgnal with a first window $w1[n]$. Said weighted PCM
signal $s^*_w[n]$ is input into a spectrum computing unit 400 for computing the spectrum $S^*[k]$
from said weighted signal. Preferably, the spectrum is computed by using the Fast Fourier
Transformation algorithm. The spectrum $S^*[k]$ is than input into the background noise
substracting unit 200 and processed therein as described above by referring to Fig. 3.

The spectrum $S^b[k]$ output by said background substracting unit 200 is input
into a re-transforming unit 500 for being transformed back into a signal $s^b[n]$ in the time
domain. In the case that the spectrum $S^*[k]$ has been calculated by using FFT the re-
transformation is done by using the inverse FFT.

The quantization noise substracting unit may further comprise a second window block 600 for generating a weighted output signal $s^b_w[n]$ by weighting the signal $s^b[n]$ received after the transformation with a second window $W2[n]$ and an overlap and add unit 700 for individually calculating a final output signal $\widehat{s}^b_w[n]$ for each frame of the PCM-signal from said weighted output signal $s^b_w[n]$ such that the transition between two successive output frames is smoothed. The first and the second window W1 and W2 are preferably identical. They are independent of the window-function $w[n]$ used for calculating the quantization noise level Bq. However, it is preferred to use the same function for $w[n]$ as for W1.

The provision of the overlap and add unit 700 only improves the quality of the output signal but it is not absolutely necessary for carrying out the quantization noise substraction; consequently, it might be left out. The same applies to the first and the second window block 300 and 600 which are both only provided to improve the operation said overlap and add unit 700.

Fig. 4 shows an example illustrating the good signal quality achieved when applying the claimed method to a μ-law coded speech signal.

More specifically, Fig. 4.1 shows the spectrum of a clean, i.e. free of quantization noise, male voice recording with the utterance: "Any dictionary will give at least twenty different definitions for it". Fig. 4.2. shows the μ-law coded version of the spectrum shown in Fig. 4.1. From that Fig. 4.2. it can be seen that said μ-law coding causes quantization noise added to the clean spectrum of Fig. 4.1. In Fig. 4.2. the quantization noise is represented by the grey-shaded areas 410; the corresponding areas in Fig. 4.1 are clean. Fig. 4.3. shows the spectrum from Fig. 4.2 after the quantization noise substracting method according to the invention has been applied. It can been seen that this spectrum substantially corresponds to original clean spectrum shown in Fig. 4.1; that means that the method according to the invention is well able to clean the spectrum of a PCM signal from quantization noise. Fig. 4.4 shows the usage array u[i] as generated by the method according to the present invention for reducing quantization noise from the spectrum shown in Fig. 4.2.